

Modelling of Single-Phase to Three-Phase Power Conversion System with Uncontrolled/Controlled Bridge at Input Side

Dheeraj Panchauli

M. Tech. Student, Rajasthan Technical University, Kota, India, dheerajpanchauli777@gmail.com

Ashok Kumar Sharma

Associate Professor, Rajasthan Technical University, Kota, India, aksharma_eck@hotmail.com

Abstract – This paper presents modelling of single phase to three phase conventional converter with uncontrolled and controlled bridge at input converter side. The input current of rectifier and output voltage of inverter is analysed. Initially single phase a.c power is converted into d.c power using diode bridge rectifier which is further converted into three phase a.c power with the help of three arms IGBT Inverter Bridge. A DC-link capacitor, is interlinked between the two stages of power conversion. The Pulse Width Modulation (PWM) control and Hysteresis Current Control (HCC) techniques have been used in rectification and inversion processes. The proposed topology permits to reduce the rectifier switch currents, the harmonic distortion at the input converter side, and improves the fault tolerance characteristics. The model is developed with the help of SIMULINK tool box of the MATLAB software.

Keyword – Power conversion, Power electronics converters, Parallel converter, Pulse width modulation.

1. INTRODUCTION

In the power distribution system, the single phase grid is considered as an alternative for rural or remote areas due to its lower cost, compared to the three phase grid. On the other hand, loads connected in a three phase arrangement presents some advantages when compared to single phase loads. Three phase motor system with variable-speed drives has advantage due to their constant torque characteristics. so there is a need for single phase to three phase power conversion system for above purpose. The direct solutions for the single-phase to three-phase power converters is presented in Fig. 1.1.

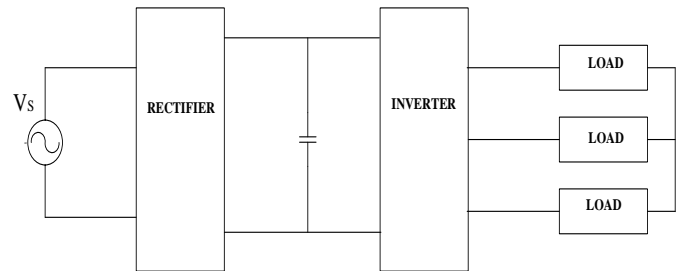


Fig. 1.1. Block diagram of single phase to three phase power converter

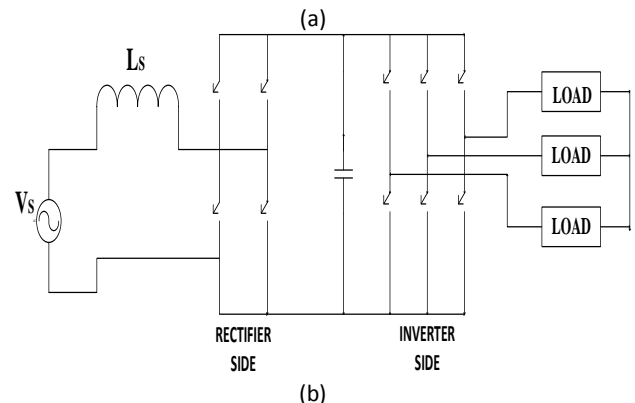
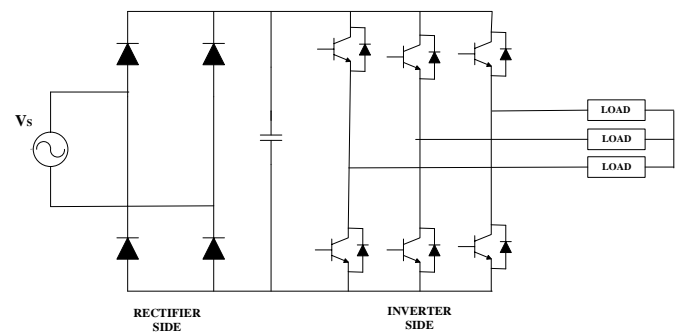


Fig. 1.2. Conventional single-phase to three-phase drive system with (a) uncontrolled (b) rectifier controlled rectifier

Standard Configuration with Conventional Controlled / Uncontrolled Switch are shown in fig. 1.2. Fig. 1.2 (b) shows a solution for single-phase to three-phase power

conversion, in which all variables (e.g., input power factor and dc-link voltage) at input-output converter sides can be controlled. On the other hand, the configuration presented in Fig. 1(a) represents a cheaper solution but without any control of the input current and dc-link voltage. This is essential in some applications such as aerospace, wind turbine, or UPS for main frame computers and servers. the proposed system permits: to reduce the rectifier switch currents; the total harmonic distortion (THD) of the grid current with same switching frequency or the switching frequency with same THD of the grid current; and to increase the fault tolerance characteristics.

2. SYSTEM MODEL

This section will present the model of the proposed configuration. Such a configuration is constituted by a single-phase grid, one open-end three-phase motor, inductor filters (L_{1a} , L_{1b}), converters 1, 2 and one dc-link capacitor banks (C_{12}). If the legs are substituted by pulsed voltage sources, the proposed converter can be modelled as in Fig.2.1.

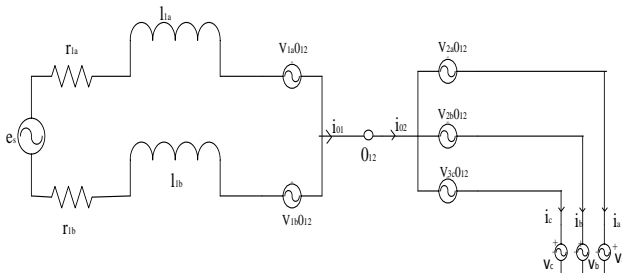


Fig. 2.1. Simplified model of the single-phase to three-phase conversion system C1 configuration

2.1. Source -Side Converter Model

From the system in Fig. 2.1, the following equations can be derived to converters 1 at the grid side:

$$e_g = r_{1a} i_{1a} + L_{1a} \frac{di_{1a}}{dt} - r_{1b} i_{1b} - L_{1b} \frac{di_{1b}}{dt} + v_1 \quad (1)$$

$$i_g = i_{1a} \quad (2)$$

With

$$v_1 = v_{1a} 0_{12} - v_{1b} 0_{12} \quad (3)$$

Where i_{1a} and i_{1b} are the input currents of the converter 1, the symbols r and L represent the resistance and inductance of inductors L_{1a} , L_{1b} . The voltages $v_{1a} 0_{12}$ and $v_{1b} 0_{12}$ are the pole voltages of the converter 1, and I_s is the source current.

2.2. Machine-Side Converter Model

From the system in Fig.2.1, the following equations can be derived to converters 2 at the machine side:

$$v_{ab} = v_{2a} 0_{12} - v_{2b} 0_{12} \quad (4)$$

$$v_{bc} = v_{2b} 0_{12} - v_{2c} 0_{12} \quad (5)$$

$$v_{ca} = v_{2c} 0_{12} - v_{2a} 0_{12} \quad (6)$$

Where $v_{2a} 0_{12}$, $v_{2b} 0_{12}$, and $v_{2c} 0_{12}$ are the pole voltages of converter 2, and $v_{ab} = v_a - v_b$, $v_{bc} = v_b - v_c$, and $v_{ca} = v_c - v_a$ are line-to-line voltages of the machine. For the voltage control of the motor, the following relations are obtained:

$$v_{2ab} = v_{2a} 0_{12} - v_{2b} 0_{12} = \frac{v_{ab}}{2} \quad (7)$$

$$v_{2bc} = v_{2b} 0_{12} - v_{2c} 0_{12} = \frac{v_{bc}}{2} \quad (8)$$

$$v_{2ca} = v_{2c} 0_{12} - v_{2a} 0_{12} = \frac{v_{ca}}{2} \quad (9)$$

2.3. Circulating Current Model

Due to the series connection, the proposed system shown in Fig.2.1 has a circulating current among the converts. The model of this circulating current can be defined as following:

$$0 = v_{za} + v_{1a} 0_{12} + v_{2j} 0_{12} + v_j \quad (10)$$

$$0 = v_{zb} + v_{1b} 0_{12} + v_{2j} 0_{12} + v_j \quad (11)$$

With $j = a, b, c$ and

$$v_{za} = r_{1a} i_{1a} + L_{1a} \frac{di_{1a}}{dt} \quad (12)$$

$$v_{zb} = r_{1b} i_{1b} + L_{1b} \frac{di_{1b}}{dt} \quad (13)$$

The equations of the input circulating currents of the converters 1 i_{o1} and output circulating currents of the converters 2 i_{o2} are defined as

$$i_{o1} = i_{1a} + i_{1b} \quad (14)$$

$$i_{o2} = i_{2a} + i_{2b} + i_{2c} \quad (15)$$

However, the circulating currents i_{o1} , i_{o2} , can be represented by a single circulating current i_o , which means

$$i_o = i_{o1} = i_{o2} \quad (16)$$

From (10) and (11), it is possible to write

$$v_o = v_{o1} + r_{1b} i_o + L_{1b} \frac{di_o}{dt} + \frac{2}{3} \sum_{j=a}^c v_j \quad (17)$$

With

$$v_{o1} = (r_{1a} - r_{1b}) i_{1a} + (L_{1a} - L_{1b}) \frac{di_{1a}}{dt} \quad (18)$$

$$v_o = \sum_{i=a}^b v_{1i} 0_{12} + \frac{2}{3} \sum_{j=a}^c v_{2j} 0_{12} \quad (19)$$

2.4. Three-Phase Motor Model

A typical three-phase machine has been used in this study. Selecting a fixed coordinate reference frame, the mathematical model that describes the dynamic behavior of the three-phase induction motor is given by

$$v_{sdq} = r_s i_{sdq} + \frac{d\phi_{sdq}}{dt} \quad (20)$$

$$v_{rdq} = r_r i_{rdq} + \frac{d\phi_{rdq}}{dt} - j\omega_r \phi_{rdq} \quad (21)$$

$$\phi_{sdq} = l_s i_{sdq} + l_{sr} i_{rdq} \quad (22)$$

$$\phi_{rdq} = l_{sr} i_{sdq} + l_r i_{rdq} \quad (23)$$

$$v_{s0} = r_s i_{s0} + l_s \frac{di_{s0}}{dt} \quad (24)$$

$$v_{r0} = r_r i_{r0} + l_r \frac{di_{r0}}{dt} \quad (25)$$

$$T_e = P l_{sr} (i_{sq} i_{rd} - i_{sd} i_{rq}) \quad (26)$$

where $v_{sdq} = v_{sd} + jv_{sq}$, $i_{sdq} = i_{sd} + ji_{sq}$, and $\phi_{sdq} = \phi_{sd} + j\phi_{sq}$ are the voltage, current, and flux dq vectors of the stator, respectively; v_{s0} and i_{s0} are the homopolar voltage and current of the stator, respectively (the equivalent rotor variables are obtained by replacing the subscript s by r); T_e is the electromagnetic torque; ω_r is the angular frequency of the rotor; r_s and r_r are the stator and rotor resistances; l_s , l_{ls} , l_r , and l_{lr} are the self and leakage inductance of the stator and rotor, respectively; l_{sr} is the mutual inductance and P is the number of pole pairs of the machine. The dqo stator variables of the previous model can be determined from the abc variables by using the transformation given by

$$\omega_{sdq0} = A_s \omega_{abc} \quad (27)$$

$$\text{With } \omega_{sdq0} = \begin{bmatrix} \omega_{sd} & \omega_{sq} & \omega_{s0} \end{bmatrix}^T,$$

$$\omega_{abc} = [\omega_a \ \omega_b \ \omega_c]^T \text{ and}$$

$$A_s = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \\ \frac{\sqrt{2}}{2} & \frac{\sqrt{2}}{2} & \frac{\sqrt{2}}{2} \end{bmatrix}$$

3. CONTROL STRATEGY

The control signals are obtained by comparing pole voltages with one (vt1), or more high-frequency triangular carrier signals. In the case of double-carrier approach, the phase shift of the two triangular carrier signals (vt1 and vt2) is 180°. The parameter μ changes the place of the voltage pulses related to V_a and V_b . When $V_x^* = V_{x\min}$ ($\mu = 0$) or $V_x^* = V_{x\max}$ ($\mu = 1$) are selected, the pulses are placed in the beginning or in the end of half period (T_s) of the control block diagram of Fig. 3.1, highlighting the control of the rectifier. To control the dc-link voltage and to guarantee the grid

power factor close to one. Additionally, the circulating current I_o in the rectifier of the proposed system needs to be controlled.

the dc-link voltage v_c is adjusted to its reference value v_c^* using the controller R_c , which is a standard PI type controller. This controller provides the amplitude of the reference grid current I_s^* . To control power factor and harmonics in the grid side, the instantaneous reference current I_s^* must be synchronized with voltage e.g., as given in the voltage-oriented control (VOC) for three-phase system. This is obtained via blocks $Ge\text{-}ig$, based on a PLL scheme Fig 3.1. The reference currents I_a^* and I_b^* are obtained by making $I_a^* = I_b^* = I_s^* / 2$, which means that each rectifier receives half of the grid current. The control of the rectifier currents is implemented using the controllers indicated by blocks R_a and R_b . These current controllers define the input reference voltages V_a^* and V_b^* . The homo polar current is measured (I_o) and compared to its reference ($I_o^* = 0$). The error is the input of PI controller R_o , that determines the voltage V_o^* . The motor three-phase voltages are supplied from the inverter (VSI). Block VSI-Ctr indicates the inverter and its control. The control system is composed of the PWM command and a torque/flux control strategy.

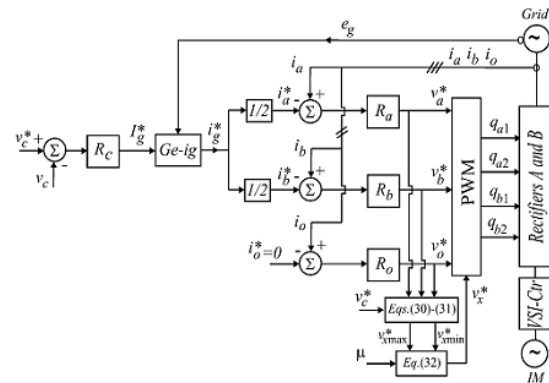


Fig. 3.1. Control block diagram

4. HARMONIC DISTORTION

As we know that harmonic distortion of the proposed converter and its voltages had been analysed with the help of weighted THD (WTHD). It is solved by using

$$WTHD(p) = 100/a_1 \sqrt{\sum_{i=2}^p (a_i/i)^2}$$

Where a_1 is treated as amplitude of fundamental voltage and a_i is treated as amplitude of i th harmonic and also p may be number of harmonics in this consideration.

5. SIMULATION MODEL

To study the operation of the Three-Phase Drive System, it is implemented in MATLAB/SIMULINK environment. The model is shown in Fig.5.1

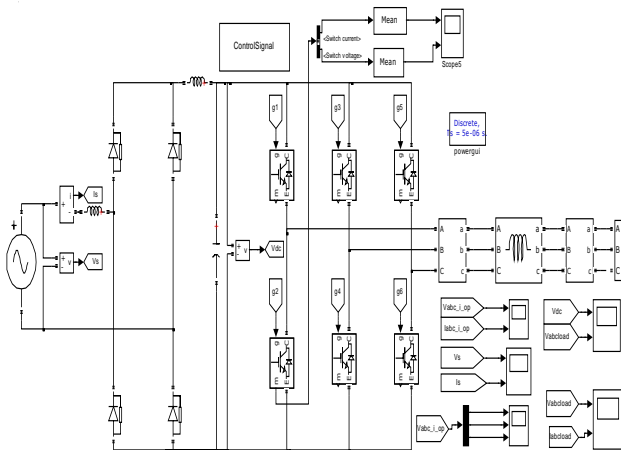


Fig.5.1. Simulation model of C1 configuration with uncontrolled bridge at input side for resistive load

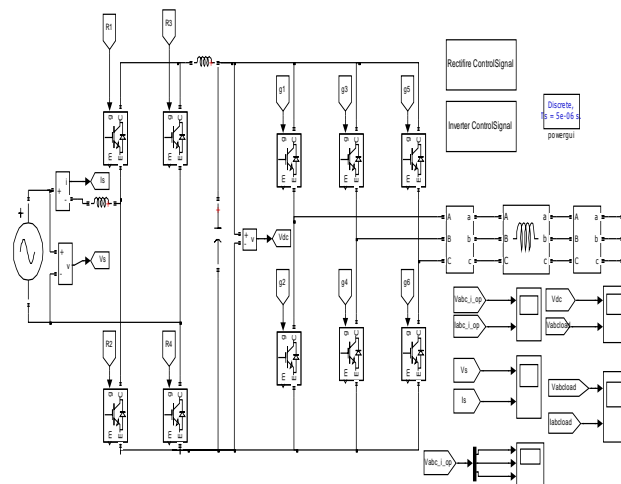
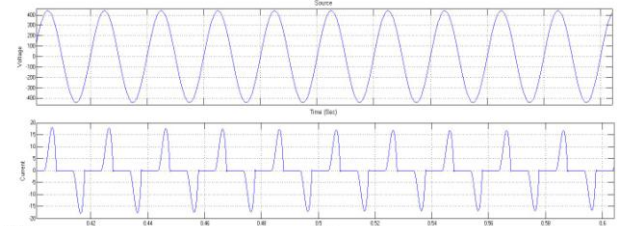


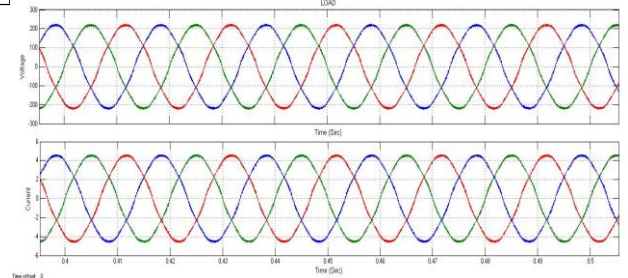
Fig.5.2. Simulation model of C2 configuration with controlled bridge at input side for resistive load

6. RESULT

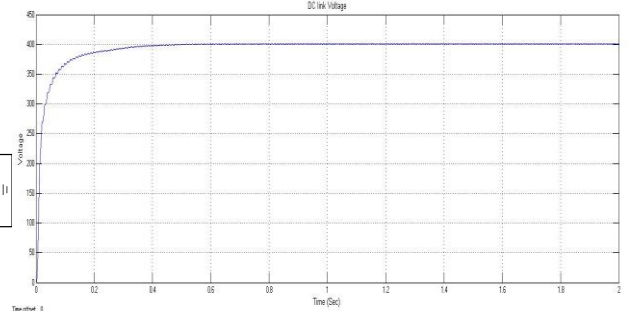
The simulation results were obtained with the source and load -phase voltages equal to $V_{rms}440/\sqrt{2}$, dc-link voltage of 400 V, capacitance of 2200 μF , and input inductor filters with resistance and inductance given respectively by 0.1 Ω and 2.6 mH. Fig. 6.1 (a) shows the ability of the conventional converter with uncontrolled bridge at input side to control the source current with a sinusoidal waveform and power factor close to one. While Fig. 6.1 (b) and (c) shows that wave form of Output Voltage and Output Current. And DC-link voltage for conventional system. Fig. 6.2 shows the wave form of source Voltage and source Current, Output Voltage and Output Current and DC-link voltage for with controlled bridge at input side



(a)

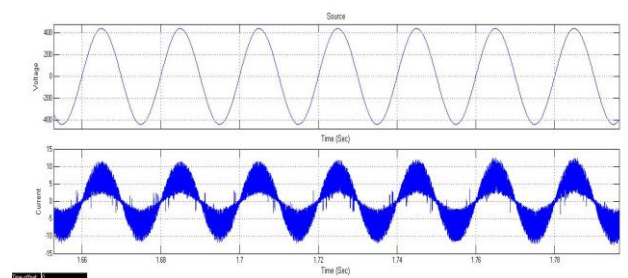


(b)

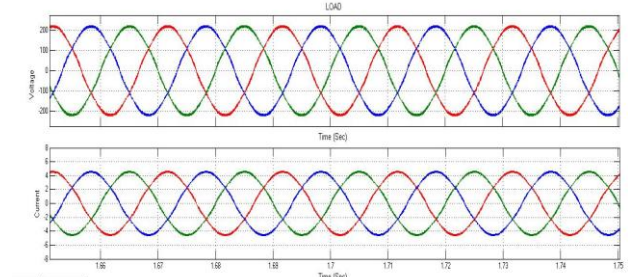


(c)

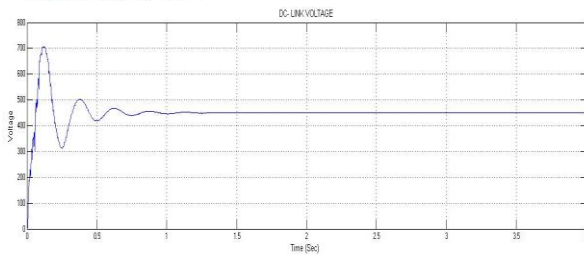
Fig. 6.1. Simulation results for conventional converter with uncontrolled bridge at input side: (a) voltage and current of the grid, (b) Output Voltage and Output Current, (C) DC- link Voltage



(a)



(b)



(c)

Fig. 6.2. Simulation results for conventional converter with controlled bridge at input side (a) voltage and current of the grid (b) Output Voltage and Output Current, (C) DC- link Voltage

7. CONCLUSION

A single-phase to three-phase drive system with uncontrolled/controlled bridge at input side and a three phase load was proposed. The system model and the control strategy, including the PWM technique, have been developed. The complete comparison between the proposed and standard configurations has been carried out in this paper. Compared to the conventional topology, the proposed system permits to reduce the rectifier switch currents, the THD of the grid current with same switching frequency or the switching frequency with same THD of the grid current and to increase the fault tolerance characteristics. In addition, the losses of the proposed system may be lower than that of the conventional counterpart. The initial investment of the proposed system (due to control of semiconductor devices) cannot be considered a drawback, especially considering the scenario where the cited advantages justify such initial investment. The experimental results have shown that the system is controlled properly, even with transient and occurrence of fault.

REFERENCE

- [1] A. H. Maggs, "Single-phase to three-phase conversion by the ferrarisarno system," *Electr. Eng.—Part I, General, J. Inst.*, vol. 93, no. 32, pp.133–136, Aug. 1946.
- [2] K. Hisano, H. Kobayashi, and T. Kobayashi, "A new type single-phase to three-phase converter," *IEEE Trans. Magn.*, vol. 2, no. 3, pp. 643–647, Sep. 1966.
- [3] S. Dewan and M. Showleh, "A novel static single-to three-phase converter," *IEEE Trans. Magn.*, vol. 17, no. 6, pp. 3287–3289, Nov. 1981.
- [4] M. Liserre, "Dr. Bimal K. Bose: A reference for generations [editor's column]," *IEEE Ind. Electron. Mag.*, vol. 3, no. 2, pp. 2–5, Jun. 2009.
- [5] F. Blaabjerg, A. Consoli, J. A. Ferreira, and J. D. van Wyk, "The future of electronic power processing and conversion," *IEEE Trans. Ind. Appl.*, vol. 41, no. 1, pp. 3–8, Jan./Feb. 2005.
- [6] F. W. Gutzwiller, "Thyristors and rectifier diodes—the semiconductor workhorses," *IEEE Spectrum*, vol. 4, no. 8, pp. 102–111, Aug. 1967.
- [7] A. Elasser, M. H. Kheraluwala, M. Ghezzi, R. L. Steigerwald, N. A. Evers, J. Kretschmer, and T. P. Chow, "A comparative evaluation of new silicon carbide diodes and state-of-the-art silicon diodes for power electronic applications," *IEEE Trans. Indust. Appl.*, vol. 39, no. 4, pp. 915– 921, Jul./Aug. 2003.
- [8] M.-K. Nguyen, Y.-G. Jung, and Y.-C. Lim, "Single-phase AC–AC converter based on quasi-z-source topology," *IEEE Trans. Power Electron.*, vol. 25, no. 8, pp. 2200–2210, Aug. 2010.
- [9] M.-K. Nguyen, Y. cheol Lim, and Y.-J. Kim, "A modified single-phase quasi-z-source AC–AC converter," *IEEE Trans. Power Electron.*, vol. 27, no. 1, pp. 201–210, Jan. 2012.
- [10] B. Saint, "Rural distribution system planning using smart grid technologies," in *Proc. Rural Electric Power Conf.*, Apr. 2009, pp. B3-1–B3-8.
- [11] A. R. C. de Lima Montenegro Duarte, U. H. Bezerra, M. E. de Lima Tostes, and G. N. da Rocha Filho, "Alternative energy sources in the Amazon," *IEEE Power Energy Mag.*, vol. 5, no. 1, pp. 51–57, Jan./Feb. 2007.
- [12] X. Wang, H. Zhong, Y. Yang, and X. Mu, "Study of a novel energy efficient single-phase induction motor with three series-connected windings and two capacitors," *IEEE Trans. Energy Convers.*, vol. 25, no. 2, pp. 433– 440, Jun. 2010.
- [13] M. Khan, I. Husain, and Y. Sozer, "Integrated electric motor drive and power electronics for bidirectional power flow between the electric vehicle and DC or AC grid," *IEEE Trans. Power Electron.*, vol. 28, no. 12, pp. 5774–5783, Dec. 2013.
- [14] Y.-S. Lai, W.-T. Lee, Y.-K. Lin, and J.-F. Tsai, "Integrated inverter/converter circuit and control technique of motor drives with dual mode control for EV/HEV applications," *IEEE Trans. Power Electron.*, vol. 29, no. 3, pp. 1358–1365, Mar. 2014.
- [15] C. B. Jacobina, E. C. dos Santos, Jr, N. Rocha, and E. L. Lopes Fabricio, "Single-phase to three-phase drive system using two parallel single-phase rectifiers," *IEEE Trans. Power Electron.*, vol. 25, no. 5, pp. 1285–1295, May 2010.
- [16] C. Jacobina, E. Cipriano dos Santos, N. Rocha, de Sa, B. Gouveia, and E. da Silva, "Reversible ac drive systems based on parallel ac-ac dc-link converters," *IEEE Trans. Ind. Appl.*, vol. 46, no. 4, pp. 1456–1467, Jul./Aug. 2010.
- [17] Y. Ohnuma and J. I. Itoh, "A control method for a single-to-three-phase power converter with an active buffer and a charge circuit," in *Proc. Energy Convers. Congr. Expo.*, Sep. 2010, pp. 1801–1807.

- [18] Y. Ohnuma and J. Itoh, "Space vector modulation for a single phase to three phase converter using an active buffer," in Proc. Int. Power Electron. Conf., Jun. 2010, pp. 574–580.
- [19] J. Holtz, "Pulse width modulation for electronic power conversion," Proc. IEEE, vol. 82, no. 8, pp. 1194–1214, Aug. 1994.
- [20] A. M. Trzynadlowski, R. L. Kirlin, and S. F. Legowski, "Space vector PWM technique with minimum switching losses and a variable pulse rate," IEEE Trans. Ind. Electron., vol. 44, no. 2, pp. 173–181, Apr. 1997.
- [21] O. Ojo and P. M. Kshirsagar, "Concise modulation strategies for four-leg voltage source inverters," IEEE Trans. Power Electron., vol. 19, no. 1, pp. 46–53, Jan. 2004.
- [22] C. B. Jacobina, A. M. N. Lima, E. R. C. da Silva, R. N. C. Alves, and P. F. Seixas, "Digital scalar pulse-width modulation: A simple approach to introduce non-sinusoidal modulating waveforms," IEEE Trans. Power Electron., vol. 16, no. 3, pp. 351–359, May 2001.
- [23] M. Malinowski, M. P. Kazmierkowski, and A. M. Trzynadlowski, "A comparative study of control techniques for PWM rectifiers in AC adjustable speed drives," IEEE Trans. Power Electron., vol. 18, no. 6, pp. 1390–1396, Nov. 2003.
- [24] P. Verdelho and G. D. Marques, "Four-wire current-regulated PWM voltage converter," IEEE Trans. Ind. Electron., vol. 45, no. 5, pp. 761–770, Oct. 1998.
- [25] H. Abu-Rub, J. Guzinski, Z. Krzeminski, and H. Toliyat, "Predictive current control of voltage-source inverters," IEEE Trans. Ind. Electron., vol. 51, no. 3, pp. 585–593, Jun. 2004.
- [26] G. Dong and O. Ojo, "Current regulation in four-leg voltage-source converters," IEEE Trans. Ind. Electron., vol. 54, no. 4, pp. 2095–2105, Aug. 2007.
- [27] C. B. Jacobina, M. B. de R. Correa, R. F. Pinheiro, E. R. C. da Silva, and A. M. N. Lima, "Modeling and control of unbalanced three-phase systems containing PWM converters," IEEE Trans. Ind. Appl., vol. 37, no. 6, pp. 1807–1816, Nov./Dec. 2001.
- [28] P. Enjeti and A. Rahman, "A new single phase to three phase converter with active input current shaping for low cost AC motor drives," IEEE Trans. Ind. Appl., vol. 29, no. 2, pp. 806–813, Jul./Aug. 1993.
- [29] J. Itoh and K. Fujita, "Novel unity power factor circuits using zero-vector control for single-phase input systems," IEEE Trans. Power Electron., vol. 15, no. 1, pp. 36–43, Jan. 2000.
- [30] B. K. Lee, B. Fahimi, and M. Ehsani, "Overview of reduced parts converter topologies for AC motor drives," in Proc. IEEE PESC, 2001, pp. 2019–2024.
- [31] C. B. Jacobina, M. B. de R. Correa, A. M. N. Lima, and E. R. C. da Silva, "AC motor drive systems with a reduced switch count converter," IEEE Trans. Ind. Appl., vol. 39, no. 5, pp. 1333–1342, Sep./Oct. 2003.
- [32] R. Q. Machado, S. Buso, and J. A. Pomilio, "A line-interactive single phase to three-phase converter system," IEEE Trans. Power Electron., vol. 21, no. 6, pp. 1628–1636, May 2006.
- [33] O. Ojo, W. Zhiqiao, G. Dong, and S. Asuri, "High-performance speedsensorless control of an induction motor drive using a minimalist singlephase PWM converter," IEEE Trans. Ind. Appl., vol. 41, no. 4, pp. 996–1004, Jul./Aug. 2005.
- [34] J. R. Rodríguez, J. W. Dixon, J. R. Espinoza, J. Pontt, and P. Lezana, "PWM regenerative rectifiers: State of the art," IEEE Trans. Ind. Electron., vol. 52, no. 1, pp. 5–22, Feb. 2005.
- [35] M. N. Uddin, T. S. Radwan, and M. A. Rahman, "Fuzzy-logic-controllerbased cost-effective four-switch three-phase inverter-fed IPM synchronous motor drive system," IEEE Trans. Ind. Appl., vol. 42, no. 1, pp. 21–30, Jan./Feb. 2006.
- [36] D.-C. Lee and Y.-S. Kim, "Control of single-phase-to-three-phase AC/DC/AC PWM converters for induction motor drives," IEEE Trans. Ind. Electron., vol. 54, no. 2, pp. 797–804, Apr. 2007.
- [37] L. Asiminoaei, E. Aeloiza, P. N. Enjeti, F. Blaabjerg, and G. Danfoss, "Shunt active-power-filter topology based on parallel interleaved inverters," IEEE Trans. Ind. Electron., vol. 55, no. 3, pp. 1175–1189, Mar. 2008.
- [38] M. Ashari, W. L. Keerthipala, and C. V. Nayar, "A single phase parallelly connected uninterruptible power supply/demand side management system," IEEE Trans. Energy Convers., vol. 15, no. 1, pp. 97–102, Mar. 2000.
- [39] L. Woo-Cheol, L. Taeck-Kie, and H. Dong-Seok, "A three-phase parallel active power filter operating with PCC voltage compensation with consideration for an unbalanced load," IEEE Trans. Power Electron., vol. 17, no. 5, pp. 807–814, Sep. 2002.
- [40] M. Pascual, G. Garcera, E. Figueres, and F. Gonzalez-Espin, "Robust model-following control of parallel UPS single-phase inverters," IEEE Trans. Ind. Electron., vol. 55, no. 8, pp. 2870–2883, Aug. 2008.
- [41] S. Kwak and H. Toliyat, "An approach to fault-tolerant three-phase matrix converter drives," IEEE Trans. Energy Convers., vol. 22, no. 4, pp. 855–863, Dec. 2003.
- [42] D. Campos-Delgado, D. Espinoza-Trejo, and E. Palacios, "Fault-tolerant control in variable speed drives: A survey," IET Elect. Power Appl., vol. 2, no. 2, pp. 121–134, Mar. 2008.

- [43] SEMIKRON Products, 2009. [Online]. Available: <http://www.semikron.com>
- [44] R. Q. Machado, S. Buso, J. A. Pomilio, and F. P. Marafao, "Three-phase to single-phase direct connection rural cogeneration systems," in Proc. IEEE APEC, 2005, pp. 1547–1553.
- [45] D. C. White and H. H. Woodson, Electromechanical Energy Conversion. New York: Wiley, 1959.

AUTHOR'S PROFILE



Dheeraj Panchauli was born in Rajasthan, India on May 1989. He completed his B. Tech. (Hons) Electrical Engineering in 2012 from Rajasthan Technical University, Kota, India. Presently he is a student of M. Tech. (Power Electronic and Electric

Drives) at Rajasthan Technical University, Kota, India. His research interests include Power electronics converters for various applications and renewable energy technology.



A. K. Sharma was born in Gangapur City, India, in 1962. He received B. E. (Hons.) in Electrical Engineering from M. B. M. Engineering College, Jodhpur, India, in 1986 and M. E. with specialization in Power

Apparatus in Electric Drives from University of Roorkee (Presently I. I. T. Roorkee), Roorkee, India in 1993. Presently he is Associate Professor in Department of Electrical Engineering, Rajasthan Technical University, Kota, India. He has published many research papers in International and National Journals/Conferences. He has guided M.E./M.Tech. Dissertations. His fields of interest include power electronics, electrical machines, electric drives, renewable energy generation, power quality, flexible ac transmission systems, and high voltage direct current transmission systems. He is life member of Indian Society of Technical Education (ISTE), Indian Society of Lighting Engineers (ISLE). Fellow member and Chartered Engineer Institution of Engineers (India). A. K. Sharma received Best Paper Award in December 2013 IEEE International Conference on Electrical, Electronics and System Engineering, Kuala Lumpur, Malaysia. A. K. Sharma is at Department of Electrical Engineering, Rajasthan Technical University, Kota, India 324010 or at aksharma@rtu.ac.in, aksharma_eck@hotmail.com